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Cold Start Concept (CSC™) Catalysts: A Novel Solution for Emissions Control

Catalytic emission control systems are installed on nearly all vehicles produced today, in order to reduce emissions and enable compliance with legislation. Although they can achieve very high efficiencies once they reach their operating temperatures, there is still scope for improvement during the cold start period of the vehicles. Global Emissions Management looks at developments that have improved the overall performance of aftertreatment systems for diesel–fuelled vehicles.

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Introduction

It can take more than 100 seconds for catalytic components to reach their operating temperature on a diesel engine, so it is particularly challenging to control the cold start emissions. One approach to this is to use storage components such as zeolites to store hydrocarbons (HC) and oxides of nitrogen (NO_x) before releasing them when exhaust temperatures enable the catalysts to start working.

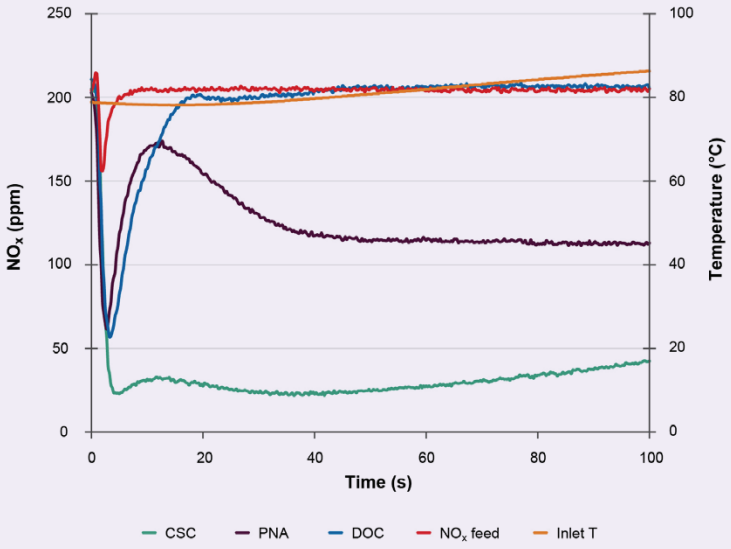
NO_x adsorber catalysts (NACs) and passive NO_x adsorber catalysts (PNAs) are both able to store NO_x under certain conditions, but both have their limitations. NACs can store large amounts of NO_x when fully regenerated, but this only occurs at temperatures above 200°C and under rich conditions. PNAs can store NO_x at low temperatures and in normal lean conditions but, as the name suggests, only target the NO_x portion of the exhaust gas.

Increasingly stringent regulations demand low emissions for HC and NO_x, meaning that they have to be well controlled during the cold start period. This has led to development of Cold Start Concept (CSC™) catalysts, combining HC trapping and passive NO_x adsorption functionality as well as CO and NO oxidation. A reduced thermal mass compared to multi-catalyst systems also enables faster temperature increase for downstream components.

Testing

To demonstrate the advantages of cold start catalyst technology, CSC™ catalysts were tested under laboratory conditions and then on an engine. In the laboratory they were compared to a diesel oxidation catalyst (DOC) containing zeolites to trap HC, and to a PNA. With platinum group metal (PGM) loadings of 50g/ft³ Pt and 90g/ft³ Pd, the CSC™ catalyst contained less Pt than the DOC and less total PGM than the PNA. Catalyst cores were aged at 750°C for 16 hours for the laboratory study, and full size catalysts for the engine test were aged at 750°C for 48 hours.

Figure 1: NO_x trace at the catalyst outlet when the catalyst is exposed to 200 ppm NO at 80°C for 100 seconds



Results

Figures 1 and 2 show the relative catalyst NO_x storage performance under laboratory conditions. In Figure 1 the NO_x concentration at the catalyst outlet is shown when exposed to a feed gas containing 200ppm NO. After 20 seconds of exposure, the outlet concentration on the DOC is at the same level as the feed gas, suggesting no additional storage takes place. NO_x storage on the PNA is much higher than the DOC, although around 120ppm NO_x slips through the PNA without being trapped. In contrast less than 40ppm passes through the CSC™ catalyst over the course of the 100-second test.

In Figure 2 the trapping efficiency of the catalysts at 80°C is seen, with the cold start catalyst storing significantly higher amounts of NO_x at high trapping efficiencies than the PNA. The DOC stores a negligible amount of NO_x at very low NO_x trapping efficiencies.

After 100 seconds of low temperature exposure at 80°C, the inlet gas temperature was increased linearly to 650°C. The cold start catalyst and PNA continue to store NO_x, with the CSC™ catalyst starting to release it at 150°C. Although this is a lower temperature than the PNA starts to release NO_x, it still removes a larger amount of NO_x from the feed at temperatures below 210°C, the point at which and NO_x release would be converted by a downstream selective catalytic reduction (SCR) catalyst. When temperatures go beyond 210°C, the NO_x concentration at the outlet of the cold start catalyst remains above the inlet level until the temperature reaches 550°C, suggesting continuous release of NO_x. There also appears to be a significant amount of NO_x conversion taking place

Figure 2: Instantaneous NO_x trapping efficiency as a function of the cumulative NO_x stored on the catalyst at 80°C for the first 100 seconds

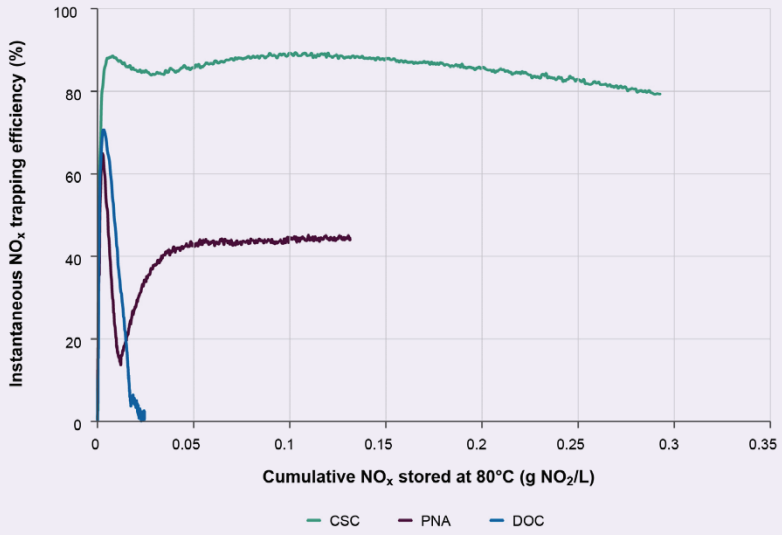
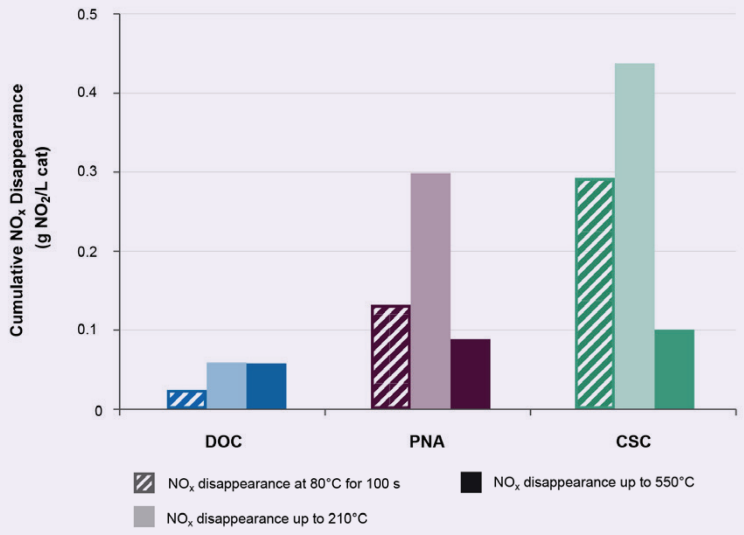


Figure 3: Cumulative (NO + NO_2 + 2xN_2O) removed by the catalyst for the first 100 seconds at 80°C (striped bars), and up to the points where the gas inlet temperatures reach 210°C (pale middle bars) and 550°C (solid colour bars)



during the temperature ramp. Figure 3 shows the amount of NO_x removed from each of the catalysts at different temperature points.

In addition to NO_x conversion and storage, it was important to test other key properties of the catalysts. A cold start catalyst has to be capable of being regenerated at normal operating temperatures, and to demonstrate this a regeneration test was conducted, taking the catalyst up to 350°C repeatedly. Similar NO_x storage capacity was seen for all of the tests, indicating that the cold start catalyst can be regenerated at temperatures within the normal operating conditions of a diesel engine.

Hydrocarbon concentrations were measured on all three catalysts, with peak HC concentration on the cold start catalyst less than half that on the DOC or PNA. This suggests superior HC storage as well as more efficient conversion of stored hydrocarbons on the CSC™ catalyst.

CO and NO oxidation activity is also excellent on the cold start catalyst, although lower than the PNA for CO and the DOC for NO. As mentioned above, the Pt loading was lower than the DOC, and the total PGM lower than the PNA, so relative performance was still very good.

The final part of the laboratory testing required sulfur tolerance and desulfation properties of the cold start catalyst to be assessed. To do this, the catalyst was exposed to high levels of sulfur and was subsequently heated to 650°C to observe how well SO_2 is released. It demonstrated good sulfur tolerance and sulphur release at around 650°C. In addition, the CSC™ catalyst was subjected to 51 repeated sulfation/desulfation cycles to test for likely real world durability. NO_x storage and release was measured after each cycle, with results showing excellent sulfur tolerance and desulfation properties.

Engine Evaluation

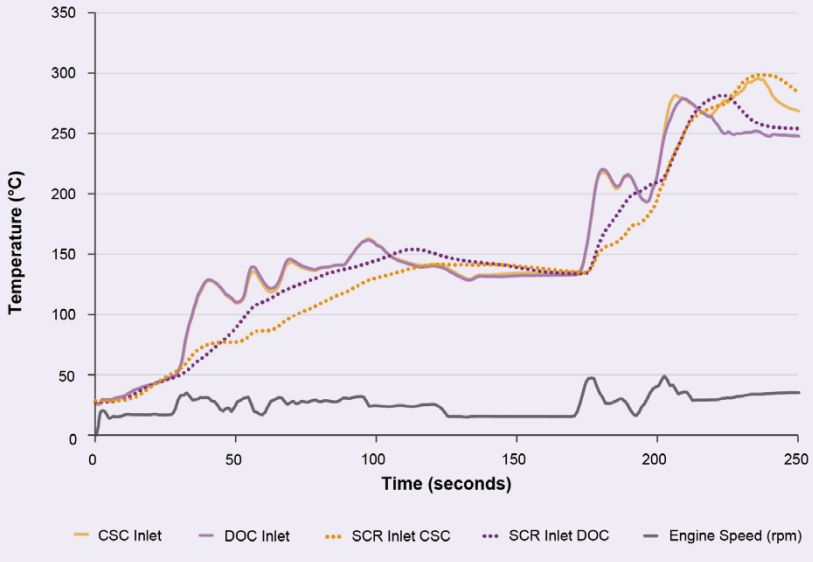
In order to demonstrate the performance of the CSC™ catalyst, a two litre part was installed on a 2011 model year light heavy duty engine along with a ten litre copper SCR catalyst. An identically sized DOC was tested to give a direct comparison with the cold start catalyst. Catalysts were tested on the LA-4 cycle to evaluate their cold start capability. Catalyst temperatures recorded during the cold start period of the tests are shown in Figure 4.

The ~220°C seen at the beginning of hill 2 is high enough for NO_x to be released from the cold start catalyst, although the SCR catalyst inlet is only around 150°C. Because urea does not reduce NO_x at this temperature, the SCR catalyst was pre-conditioned to enable ammonia to be stored on it and NO_x reduced at temperatures as low as 150°C.

Cumulative NO_x removal from the two systems is shown in Figure 5 (12), with nearly three times as much removed by the cold start catalyst in the first 170 seconds. As the temperature on the catalyst increases above 150°C, NO_x begins to release, and when it reaches 250°C the majority of NO_x is released.

NO_x starts to convert on the SCR catalyst when the temperature reaches about 150°C, and significant conversion occurs as the temperature rises beyond this. The overall contribution of the cold start catalyst to NO_x conversion is substantial, and this also applies to HC and CO. The catalyst used in the test was actually relatively small when compared with the engine displacement volume, so the catalyst volume was doubled. This had the effect of nearly doubling the cumulative NO_x removal, thereby improving the overall NO_x removal efficiency of the system.

Figure 4: Exhaust temperature profile during a cold start LA-4 test on a diesel engine test. Configuration was a (cold start catalyst + SCR) or (DOC + SCR)



Summary

Johnson Matthey has developed and demonstrated a novel concept to control cold start vehicle emissions. It is capable of storing NO_x and HC at low temperatures with very high storage efficiency and capacity, for later conversion and release. Thermal stability and sulfur tolerance of the catalyst are also very good.
With the emphasis of future emissions regulations likely to increasingly focus on real world emissions, further technology developments may enable emission control systems to meet these new requirements.

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Figure 5: Cumulative grams of NO_x removed at the cold start catalyst/DOC and tailpipe locations during a cold start LA-4 engine test